REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
08/24/2000	CONFERENCE PROCEEDINGS	

4. TITLE AND SUBTITLE
AN EVALUATION OF VECTOR GEOSPATIAL DATABASES IN COCKPIT MOVING-MAP DISPLAYS TO IMPROVE PILOT PERFORMANCE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Marine Geoscience Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/PP/7440--00-0014

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
TAMMAC

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Today's military pilots are bombarded with information from moving-maps and other advanced cockpit displays. Current moving-map displays in the AV-8B Harrier and F/A-18 Hornet naval aircraft are based on scanned aeronautical charts, which are familiar to pilots but present an unalterable - and sometimes illegible - display. When mission-planning symbols (i.e., targets, threats, routes, etc.) are overlaid on these scanned-map displays, the result can be extremely cluttered. In contrast, the advent of "vector" geospatial databases offers the potential for customized moving-maps, in which user-specified geospatial features can be layered (with or without a base-map, such as satellite imagery) to suit specific mission requirements. The primary disadvantage of vector-based cockpit moving maps is the potential for increased pilot workload, unless these new map displays are carefully designed for the target user.

15. SUBJECT TERMS
maps / charts, displays, geospatial databases, situation awareness and aviation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Maura C. Lohrenz
Unclassified	Unlassified	Unclassified		6	19b. TELEPHONE NUMBER *(Include area code)* 228-688-4611

AN EVALUATION OF VECTOR GEOSPATIAL DATABASES IN COCKPIT MOVING-MAP DISPLAYS TO IMPROVE PILOT PERFORMANCE

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ABSTRACT

Today's military pilots are bombarded with information from moving-maps and other advanced cockpit displays. Current moving-map displays in the AV-8B *Harrier* and F/A-18 *Hornet* naval aircraft are based on scanned aeronautical charts, which are familiar to pilots but present an unalterable – and sometimes illegible – display. When mission-planning symbols (i.e., targets, threats, routes, etc.) are overlaid on these scanned-map displays, the result can be extremely cluttered. In contrast, the advent of "vector" geospatial databases offers the potential for customized moving-maps, in which user-specified geospatial features can be layered (with or without a base-map, such as satellite imagery) to suit specific mission requirements. The primary disadvantage of vector-based cockpit moving maps is the potential for increased pilot workload, unless these new map displays are carefully designed for the target user.

The Naval Research Laboratory (NRL) is conducting a study for the Naval Air Systems Command to demonstrate and evaluate layered, vector-based, moving maps to determine if they can provide improved tactical situational awareness to the naval aviator. All map data under consideration are National Imagery and Mapping Agency standard products, including Vector Map Levels 0 and 1 databases, Vertical Obstruction Data, and Electronic Chart Updates. This effort will build on previous NRL and Naval Air Warfare Center studies that focused on pilot preferences for various cockpit moving-map displays. This study will first establish the design of vector-based moving-map scenarios based on aircrew preferences, and then attempt to correlate pilot performance measures with the preference data.

Much of the data for this study will be gathered via Internet, to broaden participation and minimize the evaluation's impact on participants' normal operational duties. The on-line study is two-fold: (1) a survey of combat pilots, aircrew, and requirements officers to identify the most promising map data types for mission-driven vector-based moving map displays, and (2) an evaluation of interactive moving-map simulations. Part 1 will gather preference data to assist in the design of the vector-based moving-map scenarios for part 2. Part 2 will measure pilot performance to mission objectives (e.g., deviation from flight path, time-to-locate target, etc.) and correlate this performance with initial preferences.

This paper presents a design overview of the NRL vector moving-map study, as well as relevant results from our earlier preference study, emphasizing the potential impacts (both positive and negative) of customizable cockpit map displays on pilot performance, such as map flexibility *vs.* pilot workload.

Keywords: maps / charts; displays; geospatial databases; situation awareness; aviation.

INTRODUCTION

Existing cockpit map displays are based on scanned aeronautical charts, which are familiar to pilots but present an unalterable (and often-illegible) display. The scanned chart is a raster data set, as is a satellite image or digital photograph. *Raster* refers to the digital pixel-by-pixel reproduction of a picture. Symbols

on a raster image cannot be manipulated separately, since they are bound to the entire image. Thus, for example, rotating a raster image results in inverted symbols and text (Willis and Goodson, 1997).

Figure 1a illustrates several undesirable aspects of some raster chart displays, including clutter and non-standard cartography (Lohrenz, et al. 1997). Clutter results when too much information is presented on the display (Clay, 1993), which is even more apparent when threat and route symbols are displayed over the base-map (figure 1b). Non-standard cartography refers to the use of source charts with different colors, shading patterns, etc., as seen near the top of the displays in figure 1. Both problems can render a chart less effective as a situational awareness (SA) tool, due to the increased amount of time required for the pilot to comprehend and assimilate the displayed information. When the chart is moving at a high rate of speed, as in a fighter jet's moving-map, the chart's effectiveness can decrease substantially.

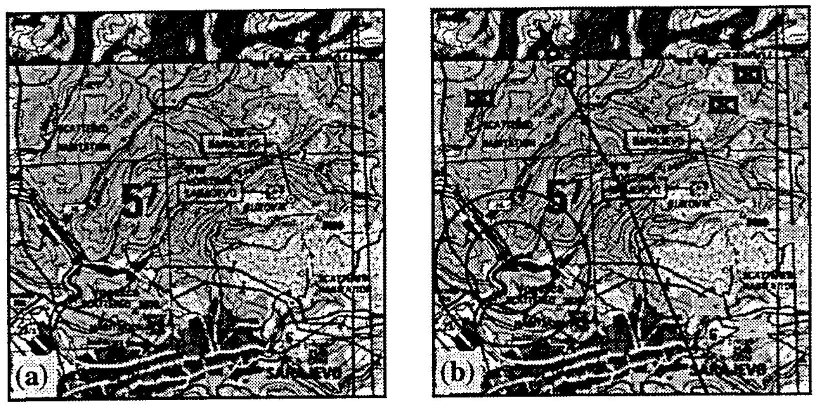

Figure 1. Sample raster chart display: (a) base-map; (b) map overlaid with mission symbols.

In contrast, vector maps offer the potential for customized displays, in which geospatial features can be layered for specific mission requirements. *Vector* refers to a relational database of such features, including points (e.g., airports), lines (e.g., roads) and areas (e.g., urban regions). Descriptive information is often tied to each feature in the database. Similar features may be stored together in themes, resulting in powerful functionality (Willis and Goodson, 1997). For example, symbols and text can remain upright while the rest of the map is rotated, since these features can be stored without respect to orientation.

Likewise, a user can display selected geospatial features and omit others, depending on the mission. Therefore, vector displays can be "decluttered" to improve a user's ability to assimilate and comprehend the information presented (figure 2). Many studies have linked display complexity to pilot performance, especially in terms of the pilot's ability to absorb and utilize the displayed information (e.g., Aretz, 1988; Schons and Wickens, 1993; Wickens and Carswell, 1995). The last two reports found that visual clutter can disrupt the pilot's visual attention, resulting in greater uncertainty concerning target locations. Or, as one pilot bluntly put it, *"If the map is too cluttered, I just turn it off!"* (Lohrenz, et al., 2000). Waruszewski (1993) determined that when a map is used as a SA tool, it must be capable of removing extraneous information. The map also should display relationships among the vehicle, surrounding threats, borders and terrain. Therefore, a vector-based map display with declutter capabilities should offer significant improvements over the current, relatively static, raster map displays.

A primary disadvantage of customizable vector moving maps (especially in a cockpit environment) is the potential for substantially increased user workload, unless these new map displays are carefully designed for the target user (Ruffner, et al., 1999; Ruffner and Trenchard, 1998). If the map display system permits too much user control, it becomes inefficient and increases pilot workload (e.g., attention to the map instead of the mission). Conversely, if the map system prohibits user control, its function as a SA tool is limited. Therefore, a careful balance between pilot workload and system flexibility is sought.

OVERVIEW OF NRL VECTOR MOVING-MAP STUDY

NRL is conducting a vector moving-map study for the Naval Air Systems Command (NAVAIR) Tactical Aircraft Moving Map Capability (TAMMAC) Integrated Product Team (IPT). The goal of the study is to establish design criteria for vector moving maps that will provide optimum SA to the aviator. This effort builds on previous Navy and Air Force studies that focused on aircrew preferences for cockpit map displays (Lohrenz, et al., 1997 and 2000; Aleva, 1999). The new study is being performed in two phases: (1) a survey of combat pilots, aircrew and requirements officers to identify the most promising geospatial features to populate mission-driven vector-based moving map displays, and (2) an evaluation of selected vector moving-map simulations. Phase 1 is gathering preference data to assist in the design of the phase 2 scenarios. Phase 2 will measure pilot performance to mission objectives (e.g., deviation from flight path, time-to-locate target, etc.) and correlate this performance with initial preferences.

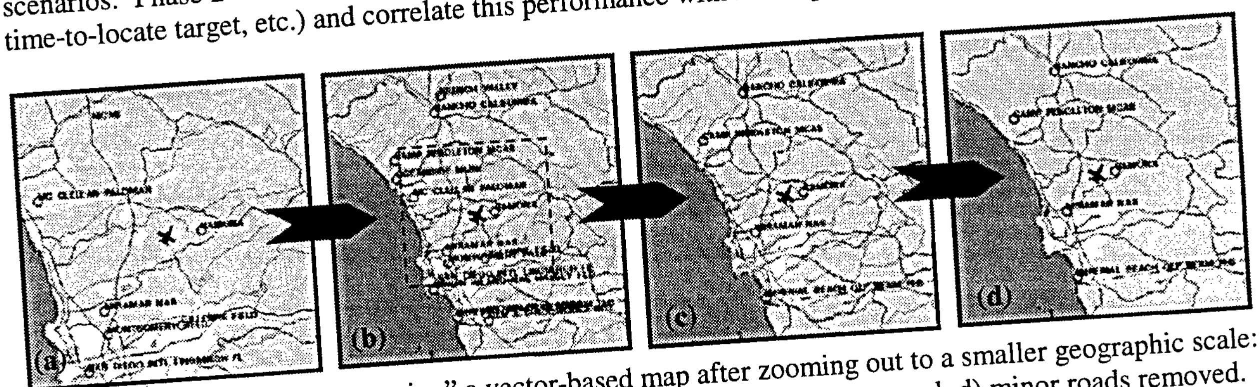

Figure 2. Example of "decluttering" a vector-based map after zooming out to a smaller geographic scale: a) pre-zoomed map; b) zoomed out 2:1; c) vegetation and some text removed; d) minor roads removed.

All preference data for this study will be gathered via Internet, to broaden participation and minimize the evaluation's impact on participants' normal operational duties. Due to time and funding constraints, previous efforts were limited to the number of participants stationed at a specific location during the scheduled survey. Thus, there were not enough participants to yield statistically significant results for the evaluations. The web-based approach should reach a much wider population in less time and at lower expense. Once established, this approach can be tailored to support future geospatial product evaluations.

PRELIMINARY RESULTS

The initial NRL study (detailed in Lohrenz, et al., 1997 and 2000), performed for the TAMMAC IPT, provided preliminary results upon which the current project can build. In the first study, 30 pilots and aircrew were grouped into three categories (tactical fighters, helicopters and Anti-Submarine Warfare (ASW) aircraft) and asked to evaluate three potential benefits of a vector moving-map:

1) The ability to keep text upright in a turn (while the map rotated in a track-up orientation);
2) The ability to selectively declutter (i.e., remove detail from) the map display (figure 2); and
3) The ability to selectively add map features to the display.

Despite the fact that fewer than 20% of participants had any prior experience with vector map displays, 80% of participants considered the demonstrated vector map to be easily interpretable, and nearly all participants rated the three demonstrated capabilities very highly for improved SA, navigation, and mission planning tasks. Partially as a result of this aircrew endorsement, NAVAIR has cited vector moving-maps as a high-priority "growth option" for the TAMMAC system. The potential value of upright text is covered in earlier reports, and this function likely will be included as a pilot-selectable option in a

future version of TAMMAC. The other two functions (decluttering and adding detail), which can be grouped together as "Map Feature Customization," suggest the need for additional research, to determine *which* map details are most important for specific air missions. This is one emphasis of the current study.

MAP FEATURE CUSTOMIZATION ISSUES

Aircrew of all three platforms (tactical, helicopter, and ASW) rated the map customization functions very highly: between 4 (*of considerable use*) and 5 (*extremely useful*) on a 5-point scale. Customizing the display (e.g., adding and removing detail) is unique to the vector map, as stated earlier. Raster images cannot support this degree of customization because the individual map features are fused into the overall image. A potential advantage of the vector map is that any combination of features can be displayed; in theory, a pilot can choose from an infinite selection of geospatial feature types.

Table 1. List of NIMA Data Types Under Consideration

Point / Gridded Data			
♦ Digital Aeronautical Flight Info. File (DAFIF)	multiple	U	
♦ Digital Point Positioning Data (DPPDB)	large-scale	S	
♦ Digital Terrain Elevation Data (DTED 1)	1:250k	U	Well-populated
(DTED 2)	1:50k	U	Sample sets only
♦ Foundation Feature Data (FFD)	multiple	U/S	Multiple data sets
Vector Data			
♦ Digital Nautical Chart (DNC)	multiple	U	
♦ Vector Smart Map (VMAP 0)	1:1M (ONC)	U	Global
(VMAP 1)	1:250k (JOG)	U	~30% global
(VMAP 2)	1:50k (TLM)	U	Sample sets only
Raster Data (e.g., as base-maps for vector overlays)			
♦ Controlled image Base (CIB)	5m, 10m res.	U	Selected coverages
♦ Compressed Arc Digitized Raster Graphics (CADRG)	multiple	U	Well-populated

All map data under consideration are National Imagery and Mapping Agency (NIMA) standard products (table 1), including point data (e.g., gridded elevations), vector data (e.g., Vector Smart Map, or VMap), and raster data (e.g., satellite imagery, as a base-map for vector overlays). VMap is the vector equivalent of the NIMA aeronautical charts currently displayed as raster images in cockpit moving-maps: VMap Level 0 is derived from the Operational Navigation Chart series, which is a 1:1,000,000 scale product; VMap Level 1 is derived from the more detailed 1:250,000 scale Joint Operational Graphics; and VMap Level 2 is derived from the very detailed 1:50,000 scale Topographic Line Maps.

In VMap Level 1 alone, there are 174 unique geospatial feature types organized into 9 thematic layers (e.g., *Boundaries*, *Hydrography*, *Transportation*, etc.; NIMA, 1997). There are additional feature types in VMap Levels 0 and 2 (although there are many features in common among the VMap levels). It is inconceivable, therefore, to imagine giving a pilot (or navigator) unlimited control over geospatial feature selection. There would be no time to fly the aircraft! Some customization must be performed before the map is loaded into the cockpit, both in the initial design of the map display system itself and later in individual mission planning sessions.

Likewise, attempting to evaluate all 174+ geospatial features via our web-based survey would be prohibitively time-consuming. The field can be narrowed in two ways: 1) grouping features into cartographic themes, as NIMA has done, and 2) prioritizing those themes (and the features within) according to anticipated mission requirements. In an effort to identify the geospatial data requirements of specific missions, the first section of our survey queries participants for their primary aircraft (e.g.,

AV-8B, F/A-18, MH-53, etc.), experience level (e.g., total flight time in the primary aircraft), and the approximate percentage of their flight time spent performing each of several missions, such as *Air Intercept*, *ASW*, *Electronic Counter Measures*, *Search and Rescue*, etc.

Our original survey loosely tied general cartographic requirements to aircraft type, but not to specific mission. For example, pilots of all three aircraft categories (tactical, helicopter, and ASW) indicated a need for vertical obstructions, Clear Line-of-Sight, threat intervisibility, and some selectable text layers. Tactical and ASW pilots suggested including the position of the nearest divert airfield, in case of emergency. Tactical and helicopter pilots required a latitude / longitude grid, terrain features (e.g., Height-Above-Terrain warnings), some sectional features, and some cultural features to the map display.

One tactical pilot stated that the map features used on current charts *"should all be available* [for adding detail]. *For example, on the chart you use for 'night low-level' you wouldn't care about railroad tracks. Whereas in 'day low-level' or 'day high-level' a railroad track is easy to see and makes for great navigation.* [Features] *need to be selectable depending on what you're trying to do."* I.e., map designers should take care not to eliminate any potentially useful information from the database that will drive the map display. Pilots need the ability to easily add new information in-flight, when required.

Given the potential workload associated with a customizable map display, we asked participants how they would envision the implementation of such a display in their cockpits. Would they prefer to manually choose the map features to be added and removed as needed, or would they prefer to have the display system "choose" the features for them? Most pilots wanted some combination of these two options, such as letting the system automatically present a "default" map display, based on the mission to be flown, which could be modified by the pilot as required. Alternatively, the pilot could pre-program various levels of declutter in mission planning, then select "declutter level 1" or "level 2" in-flight.

DESIGNING A BETTER MOVING-MAP FOR ENHANCED SA

Many SA experts include aircraft moving-map displays in their arsenal of SA tools (e.g., Gawron, 2000; Williams, 1998; Ruffner and Trenchard, 1998), especially for low-level and nap-of-the-earth flights. An improved moving-map display should address the three levels of SA, as first defined by Endsley (1988): 1) Perception of the environment; 2) Comprehension of the current situation; 3) Projection of the future.

A well-defined moving-map display can enhance Level 1 SA by assisting the pilot with location tasks, such as detecting changes in terrain elevation and locating airfields, threats, or other important features in the surrounding area. Ideally, the display should convey only the required information, since an increase in visual clutter has been shown to disrupt a pilot's visual attention, resulting in greater uncertainty concerning target locations (Wickens, 1993; Wickens and Carswell, 1995). Again, vector-based moving-maps can provide a declutter functionality; our task is to determine *what* to declutter.

The ideal moving-map display can improve Level 2 SA by assisting the pilot with integration tasks, such as understanding that rapidly rising terrain – shown on a DTED display – is a danger to low-level flight, or comprehending that a perceived object on an up-linked satellite image is, in fact, his target. The pilot's own experience contributes significantly to his ability to assess the situation (Endsley, 1997). An expert pilot – who is also very familiar with the functionalities of his moving-map – could interpret more complex displays and assimilate more geospatial features into a cohesive picture than a novice. Vector moving-map displays can be customized for the individual pilot, as well as the mission; our task is to determine *how much* customization is too much, based on pilot experience and mission workload.

Finally, the ideal moving-map can improve Level 3 SA by assisting the pilot with prediction tasks, which incorporate Levels 1 and 2. For example, the pilot might *locate* possible divert airfields along his route, *identify* whether the airfields are friendly and capable of safely accommodating his aircraft, and *predict* whether he could land at a given airfield in an emergency. The map display could provide all the necessary information (i.e., airfield location, size, hostile / friendly status) to come to a final decision.

This would be an example of an in-flight mission replan, one of many possible scenarios that might not be accounted for in the initial map display. However, if the necessary geospatial data is carried along in the aircraft computer system, the pilot can call it up as a vector feature layer on the existing map. Our task is to determine which *additional* features should be stored in memory for real-time customization in-flight.

ACKNOWLEDGEMENTS

We wish to acknowledge the contributions of the U.S. Navy's Tactical Aircraft Moving Map Capability (TAMMAC) program (NAVAIR PMA 209) and express our appreciation for the support of Ms. Sunny Even and Mr. John Hayter (current and former TAMMAC Deputy Program Managers, respectively) during the conduct of the research reported here and during the development of this paper. We also thank Dr. John Ruffner (DCS Corporation) for his continued guidance and support during this and past projects.

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4. AUTHOR 0LD05

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41029009

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An Evaluation of Vector Geospatial Databases in Cockpit Moving-map Displays to Improve Pilot Performance

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